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Bond Type Anchorage Systems for Permanent High Strength CFRP Ground Anchors

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ABSTRACT: CFRP ground anchors have an integral place in the ground anchor industry, providing designer and contractors with a corrosion resilient anchor which minimises the labour intensive corrosion protection required when using steel strands. Successful anchoring of long strand lengths in a confined ground anchor environment has been the greatest constraint in the development of CFRP ground anchors. Recent research undertaken at Monash University and Geotechnical Engineering has developed a reliable and compact bond type anchorage head system, practical for permanent ground anchor applications. Laboratory and full scale testing has been successfully carried out. This paper provides tests results on a four and ten strand CFRP modified bond type anchor head system with a reduced bond length. Results showed failure of specimens were within the CFRP fibres due to tensile rupture. Negligible movement at the bond anchor head were recorded.

1 INTRODUCTION

The applied tensile force to a ground anchor system requires to be locked off, generally at the surface of the substructural member. There are many methods to lock this applied load off, ensuring a tensile/resistive force is held, depending on structural situation. Unfortunately not all anchor head systems are applicable to FRP applications, in particular ground anchored structures.

Lateral pressures applied using a barrel and wedge system is acceptable for homogenous materials that can distribute high forces over a short length with minimal deformity and impact on performance. The barrel and wedge anchoring devises are not as acceptable to heterogeneous materials such as FRP. Due to the unidirectional strength of FRP's, applied lateral pressures can cause over stressing of the composite structure resulting in premature rupture of individual fibre tows effectively over loading the surrounding fibres and causing a premature failure within the barrel/wedge system. As presented, modification to enable the use of barrel and wedges have been investigated and developed by manufacturers. These systems rely on using a combination of soft metals sleeves bonded to the strand and oversized soft metal, variable stiffness, or non-metallic wedges to support the highly concentrated bi-directional stresses at the anchor head (Shrive et al., 2000, Reda and Shrive, 2003, Sentry et al., 2009).

Bond type anchor head systems are a successful anchoring method for FRP applications (Zhang and Benmokrane, 2004). To date, bond type anchor head systems have been large and cumbersome for ground anchor projects where area restrictions at the anchorage zone is quite common. Minimum required bond lengths for an FRP anchor head system is in excess of 500mm (ACI, 2004, Zhang and Benmokrane, 2004). Various mediums have been used including cementitious and resin based annulus with limited success in reducing these bond lengths. Research has shown that resins with low modulus of elasticity can potentially limit the peak shear stress during load transfers, while high modulus resins are more efficient at long-term creep control (Benmokrane et al., 1997). Cementitious based grouts with expansive additives perform better than standard cementitious grouts (Zhang and Benmokrane, 2002, Xue et al., 2008).

A limited number of lock-off systems have been established for bond type anchor heads, which primarily centre around using a locking nut configuration (Benmokrane et al., 2000). This paper presents alternative bond type anchoring systems that can reduce the overall bonded anchor head length.

2 MODIFIED BOND TYPE ANCHR HEAD ASSESSMENT

The patented modified bond type CFRP anchor head system (Sentry and Carrigan, 2009) was developed to ensure ultimate failure was within the CFRP strand and not the anchor head whilst minimising bond length requirements and the overall physical anchor head dimensions. The modified anchor head also established an easy method for fabrication by use of common materials including cementitious and epoxy based grouts as the primary bond agent (this paper looks only into cementitious based grout results). Tests presented are for a four and ten strand CFRP modified anchor head. Each test was conducted to ultimate capacity.

2.1 *Modified bond type anchor head materials*

The modified bond type anchor head system utilised a 15.2mm diameter CFRP strand (CFCC – Tokyo Rope) with material properties as per Table 1 (comparisons made to steel strand). The anchor head system has be manufactured from both plastics and metals; however, results presented herein are for the metallic based anchor head components (bearing plate and anchor head casing) (figure 1).

Tests are presented on a four and ten strand CFRP modified bond type anchor head system with a maximum bond length of 500mm. Bond lengths shorter than 500mm has been successfully achieved using the modified method of fabrication (Sentry, 2010).

Property	CFCC	Steel
Dimensions		
Diameter (mm)	15.2	15.2
Cross Sectional Area (mm^2)	113.6	143
Linear Weight (g/m)	226	1125
Carbon Fibre		
Minimum fibre volume ratio	0.62	-
Density (g/cm3)	1.5	-
Tensile strength (MPa)	4200	-
Elastic modulus (GPa)	240	-
Resin		
Type	Epoxy	-
Density (g/cm3)	1.6 - 2.0	-
Tensile strength (MPa)	80	-
Product		
Tensile strength (MPa)	2200	1830
Elastic modulus (GPa)	141	195

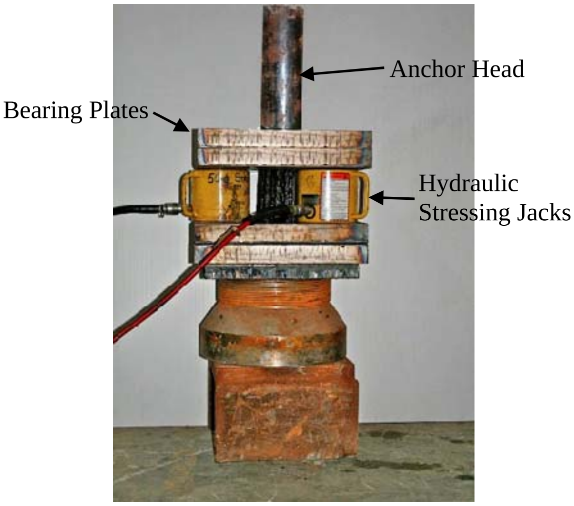

Figure 1 Test set up of modified bond type anchor head system

2.2 *Method of Assessment*

Test procedure was adopted for both four and ten strand anchor head test and comparisons made against laboratory based single strand results. Specimens were tested as per figure 1. Load was increased gradually in 7% increments of estimated ultimate load (T_{ult}). Each increment was sustained for up to five minutes prior to increasing to next increment to make observations. Test was carried out until a failure occurred. A 50mm-travel dial gauge was located on top of the anchor head to record any movement of the top anchor head unit during testing. Due to destructive nature of test, a measuring marker was located on one hydraulic jack's extension ram to record jack extensions at each load increment. Measurements were readable to 0.5mm. High speed cameras were used to visually record failure mode of the ten strand anchor head. Image speed of camera was 500 frames per second.

3 RESULTS

3.1 *Anchor head bond agent strength results*

A cementitious grout mix was used as the bond agent in the anchor head. A 28 day unconfined compressive strength tests were carried out on 50mm^3 grout cubes taken during the casting of the four and ten strand anchor head. Results showed a density of 2123kgm^{-3} and an unconfined compressive strength of 81.3MPa after 28 Days. Minimum unconfined compressive strength of 60MPa was reached after just over 48 hours.

3.2 *Four strand modified bond type anchor head*

Specimen failure was due to catastrophic rupture of the strands within the free length and at the surface of the anchor heads proximal end (figure 2). Failure was sudden across all four strands at a peak load of 1120kN (280kN/strand). Failure occurred at the peak of the elastic zone at the estimated ultimate strand system capacity (figure 3). There were no signs of radial cracking of the grout at the distal ends of the anchor head, indicating stresses within anchor head had not exceed the confined compressive strengths of the grout and the bond stresses between grout and tendon.

Peak anchor extension of 0.49mm at a load of 1040kN was recorded. Extension at peak load was unobtainable due to the destructive rupturing of the test specimen at ultimate capacity.

The measured extension results show linear elastic behaviour of the test specimen up to ultimate load (figure 3). The linear extension indicates no strand slippage was observed.

Figure 2 Failure of CFRP strand due to rupture within free length.

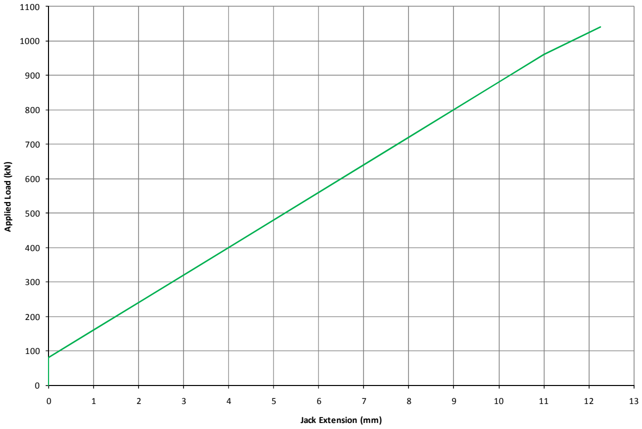

Figure 3 Applied load verses extension result for four strand CFCC anchor head test.

When comparing the applied stresses-strain against the control single strand results (Sentry, 2010) (figure 4), ultimate strain per strand in the four strand anchor head test is comparable with the single strand control results. Elasticity results are also comparable.

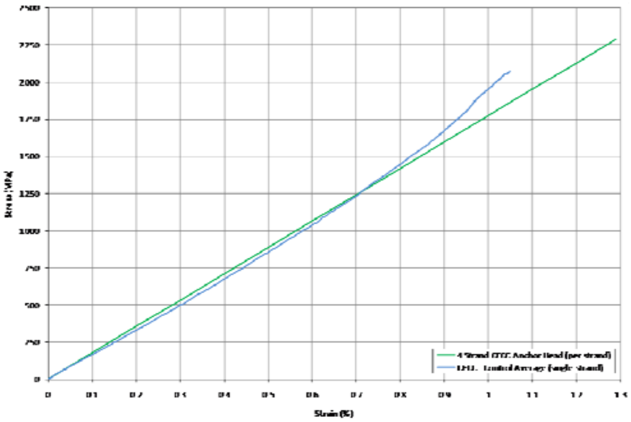

Figure 4 Stress verses strain comparison between four strand anchor head test and average single strand control specimen results.

3.3 *Ten strand modified bond type anchor head*

Specimen failure was due to catastrophic rupture of the strands within the free length at the anchor heads proximal end. Failure occurred at a peak load of 2786kN (278.6kN/strand). Ultimate stand load is comparable with the four and single strand results (Sentry, 2010).

Due to the extreme destructive nature of the ten strand test no load-extension or stress-strain results were obtainable.

Figure 5 shows the progressive rupture of strands during the final stages of loading. As one strand commenced its explosive failure, the stored energy was transferred to the surrounding strands. As these strand become over loaded, they too commenced rupturing in the same manner until complete rupture of all strands occurred. In addition to this observed phenomenon, flying debris also applied additional point load impact forces on the highly strung strands assisting in increasing the applied stresses to individual strands.

Non uniform load transfer between strands within the anchor test arrangement was captured on the high speed camera during the final loading stages of the test specimen. It was observed that this non-uniform load transfer was absorbed within the anchor head system right up to failure of the strands without any signs for bond stress failure, grout failure or CFRP failure within the anchor head unit itself.

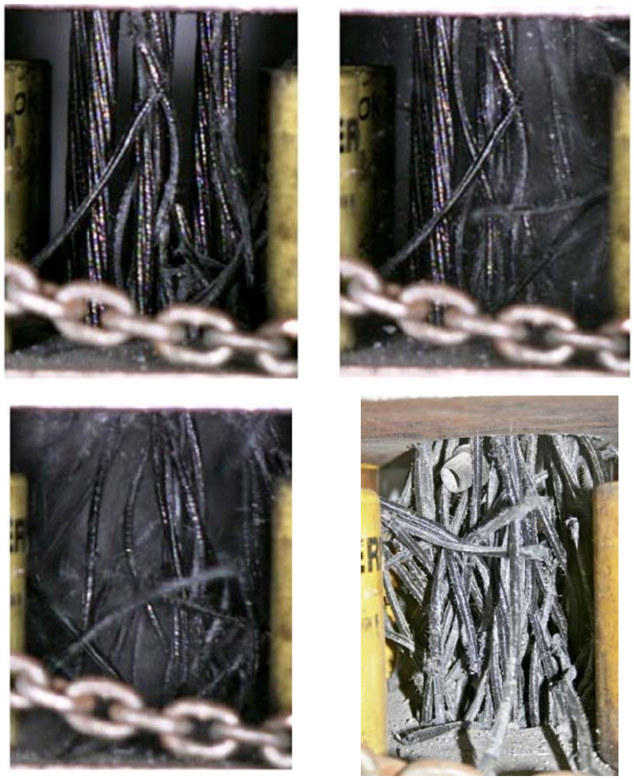

Figure 5 High speed camera images of progressive failure of ten strand modified CFRP anchor head test specimen.

4 CONCLUSION

The results from the four strand CFCC anchor head experiment shows that the modified bond type anchor head system (Sentry and Carrigan, 2009) is a successful anchor head system for FRP material whereby effective minimising of bond length is achievable.

The 10 strand anchor head test results provided a greater visual understanding in the progressive failure at ultimate strand capacity. Observations were recorded for the transfer of energy between strands as progressive strand failure occurred in the final moments prior to complete specimen strand rupture.

The cementitious grout mix used as the bonding annulus within the anchor head proved flowable enough to fully bond the strand configuration within both the four and ten strand samples with minimal voids present. Unconfined compressive strength tests were consistent between the two tests with strengths exceeding 70MPa after seven days curing. No bond stress failure was observed in both samples and no significant cracks were generated whilst specimens were under load. The cementitious grout mix provided a sound grout annulus to be able to fully anchor the required number of strands in a permanent ground anchor whilst under sustained loading.

In both tests, manufacture stand capacity was exceeded prior to fibre rupture further confirming that the ‘Modified Bond Type Anchor Head’ system is efficient and reliable at sustaining required loads without movement at the anchor head.

5 ACKNOWLEDGEMENTS

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